Towards Wearable Lightweight Assistive Robotics: Novel Actuation Principles, Applications, and Challenges

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***Abstract*—Conventional wearable robots comprised of rigid joints and links are very limited in providing proper assistance for people in need on a daily basis. Commonly used actuators and sensors make it challenging for researchers and engineers to design compact and lightweight wearable systems which would be truly mobile and non-restrictive for the wearer. In our work, we are focused on developing lightweight compliant actuators and implementation of novel actuation principles that can eliminate the use of rigid structures. We have been working on design of elbow and upper-limb exoskeletons based on cable-driven and twisted string actuators, and a prototype of such device is currently at its experimental verification stage. We would like to share our experience and point of view with clinicians, therapists and fellow engineers in order to develop practical lightweight and mobile assistive systems.**

I. INTRODUCTION

Exoskeletons are robotic systems worn by a person in such a way that the physical interface leads to a direct transfer of mechanical power between the human and environment. There are various applications in which humans may require such robotic systems, with rehabilitation and daily assistance being ones of the most significant among them.

In recent years, a number of various exoskeleton systems were developed for patients treatment and rehabilitation.

However, size, weight, lack of mobility and mechanical and control complexity of such systems often do not allow to bring them into the scenarios of daily patients treatment.

There are various robotic systems available for the use in the hospital and rehabilitation centers environment, where a patient can get treatment under the supervision of a specialist. However, in our opinion, researchers from both medical and robotics worlds should work more closely and look into ways of creating mobile wearable systems which would be able to provide necessary assistance outside hospital environment. In order to create such systems, engineers should find and implement novel actuation principles, actuators and sensors, while medical specialist can guide them in order to create an adequate final product.

In our work, we are focused on development of cable-driven, lightweight exoskeletons that can be controlled by human intention without the use of external force sensors and mechanically complex and bulky actuators, while also eliminating a need in external power source, unlike most pneumatic or hydraulic systems. One of the key parts in our cable driven systems is an implementation of the twisted string actuator.

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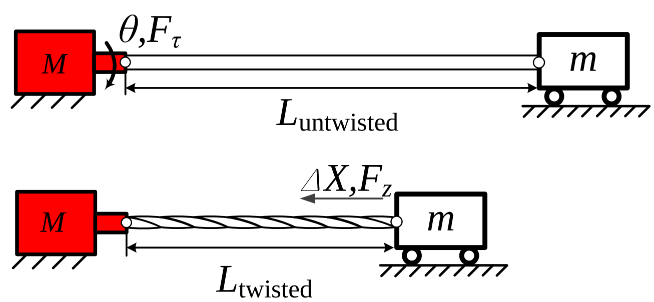

Fig. 1. Basic working principle of a twisted string actuator

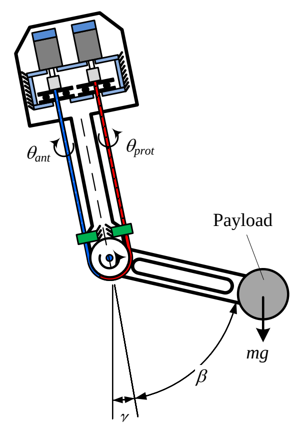

Fig. 2. Basic working principle of a bidirectional rotational joint

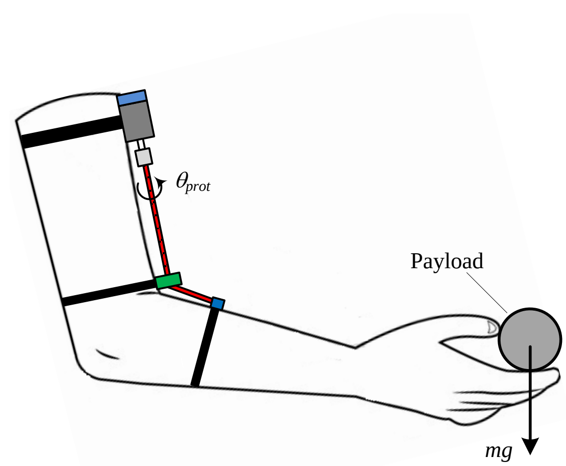

Fig. 3. Basic working principle of an elbow exoskeleton actuated by TSA

II. Twisted String Actuator

Twisted string actuator (Fig. 1) is a light, compliant and efficient mechanical actuator, where a string connected to an electric motor acts as a gear. When a load is attached to the string on the other end, the rotation imposed on the string by the motor will reduce the length of the string, thus causing the translational motion of the load due to the generated pulling force.

Advantages of twisted string actuators (TSAs) include:

- Low weight and price, quiet operation.
- Intrinsic compliance and high efficiency.
- Transmission of power over distance.

Another benefit of such actuators is that the actuators generate force coaxially with the shaft of motor, which allows to design compact drives. Throughout our work, we implemented TSAs in the following practical robotic setups:

- Linear translational joint: We improved conventional mathematical model of a twisted string which sufciently increased the correlation between experimental results and the model [1]
- A concept of bidirectional rotational joint (Fig. 2): We developed an intrinsically compliant device which was very light and utilized a pair of antagonistic TSAs. With such conguration, it was possible to control the stiffness of the joint and to estimate human intention using compliance of the TSAs , [2].This experimental setup was used in order evaluate kinematics and control law for future wearable assistive device (Fig. 3)
- Variable stiffness linear joint: We developed a mathematical model which takes into account variable stiffness of the twisted strings and makes it possible to control position and stiffness of the joint without the use of any additional position or force sensors at the load side [3].

Considering these implementations, we can foresee TSAs being used as lightweight and configurable modules in various exoskeleton systems. Since a TSA can be placed remotely from any joint that needs assistance, it may decrease overall weight of the exoskeleton system and make it more compact and mobile. For instance, all TSAs can be placed on a single rigid frame located at the back of humans body, and the forces may be transferred to the required joints by twisting cables. In this case, there is no need in rigid links connected to humans limbs since the strings and tendons can pass through Velcro-like belts, as depicted in Fig. 3. In addition, due to the variable stiffness of the twisted strings implementation of TSAs may allow to change the stiffness of certain joints of the exoskeleton smoothly without the use of any additional mechanisms. In this case, the same wearable system can be used for various rehabilitation exercises which require different levels of resistance/assistance on the daily basis.

Currently, we are working on a 3-DOF arm exoskeleton (2-DOF shoulder joint and 1-DOF elbow joint) system which will incorporate the same actuation principles as the elbow assistive device. We do not use any rigid links, which drastically decreased the weight of the wearable system and made it more comfortable for the patients. The exoskeleton have not been tested in practical rehabilitation tasks yet, and we are looking forward to clinicians' feedback.

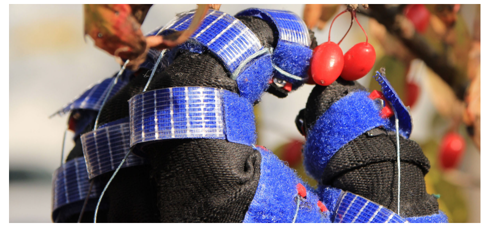

Fig. 4. Side view of the developed hand exoskeleton GraspyGlove

III. GraspyGlove

GraspyGlove is a lightweight and mobile exoskeleton glove (Fig. 4) that can be used by a patient on daily basis for assistance and rehabilitation. We developed a cable-driven soft exoskeleton that employs DC motors for finger actuation. The glove was tested in a series of grasping experiments and showed good results when manipulating both small-sized and large objects. The proposed device does not suffer from such important drawbacks of existing exoskeleton glove systems as limited motion range of the wrist, decreased mobility, and restricted palm grasping.

The characteristics of the current version of GraspyGlove are as follows:

- Maximum pinch force is 16 N
- Overall weight of the system is 300 g
- 3 fingers and thumb are actuated

The developed glove will be available for pre-order in short term. We are looking forward to raise a discussion on advantages and drawbacks of cable-driven assistive systems along with possible ways of improvement and implementations of wearable assistive and rehabilitation robots.

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